MONTHLY WEATHER REVIEW

Editor, EDGAR W. WOOLARD

VOL. 68, No. 12
W. B. No. 1315

DECEMBER 1940

CLOSED FEBRUARY 3, 1941
ISSUED MARCH 24, 1941

THE VARIABILITY OF THE THERMOELECTRIC PYRHELIOMETER FACTOR

By IRVING F. HAND

[Weather Bureau, Washington, D. C., March 1940]

For several years pyrheliometers utilizing copper-constantan thermopiles have been used by the Weather Bureau at Washington, D. C., and the Blue Hill Observatory of Harvard University at Milton, Mass., to measure normal incidence radiation. [1] In every case the readings of the thermoelectric pyrheliometers were checked against readings of substandards, chiefly the Smithsonian silver-disk and the Marvin resistance pyrheliometers, in order to determine factors by which to multiply scale readings to obtain radiation values in gram-calories. After finding that there is a change in these factors with radiation fluctuations, we began a series of comparisons late in 1938 between our substandards and the thermoelectric pyrheliometer; and a new and longer series was commenced in March 1939, after the recording micromax potentiometer had been thoroughly adjusted by factory experts. Comparisons also were made between our substandard pyrheliometers and a vacuum thermoelectric pyrheliometer [2] registering on both a micromax potentiometer and an eye-read microammeter.

The appreciable errors, introduced by the change in resistance of the elements in the vacuum thermopile with temperature variations, induced us to change from the measurement of current to the null potentiometric method. This change is appreciable because of the relatively large ratio of the resistance of the couple to that of the total circuit; that is, the resistance of the couple is 7 ohms as compared with 8 ohms of the microammeter and less than 1 ohm of the leads, while 7 ohms is the maximum resistance which we can introduce externally and still retain proper scale deflections.

Only 14 series of comparisons were made between the substandard pyrheliometers and the vacuum thermocouple recording on a microammeter, and these give a probable error of ±4.5 percent when a single mean for a full calorie range is used as a constant factor. By drawing a line of best fit through the plotted readings, the probable error is reduced to ±2.7 percent. An attempt was made to determine the effect of free-air temperature changes, but without success.

Unquestionably the effect of the Stefan-Boltzman law enters into the cause of the varying factors; but calculations from available data fail to give results comparable with the line of best fit, and it is thought, therefore, owing to lack of sufficiently precise data on the characteristics of the alloys used, the dimensions, and other quantities, that the only practical method of obtaining the factors is through a long series of direct comparisons.

[1] The first instance of this method of pyrheliometric measurement known to the writer was described by Ladislaus Gorczyński in the MONTHLY WEATHER REVIEW, 52: 299-301, June 1924.

[2] Single junction vacuum normal incidence pyrheliometer made by Leland B. Clark, of the Astrophysical Observatory of the Smithsonian Institution, Washington, D. C.

A much longer series of 337 comparisons was made between our substandard pyrheliometers and the Eppley normal incidence pyrheliometer, and 298 comparisons between the same substandard instruments and the Clark vacuum pyrheliometer, both recording on a potentiometer. Table 1 lists all comparisons and corresponding factors for both instruments; figure 1 shows a plot of the mean factors, as abscissas, against radiation values in gram calories as ordinates, for the Eppley pyrheliometer.

In the case of the Eppley pyrheliometer the probable error of a single observation from the line of best fit in the range 0.85–1.45 gram calories is ±0.37 percent, and the probable error of the means of a series of 10 is ±0.24 percent. However, if the mean value for all observations is used for a constant factor, the probable error of individual readings from this constant factor is ±1.18 percent for the same range, but somewhat larger for the entire range ordinarily covered when making normal incidence measurements from air-mass 5.0 to as close to 1.0 air mass as is practicable.

We would expect the probable error of a series to be less than that of a single observation, because radiation receipt never is uniform. Moreover, the thermoelectric records are continuous, whereas the substandard pyrheliometers give readings only every minute or every 4 minutes, depending upon the type used.

The probable errors of both instruments with various combinations are tabulated in table 2.

TABLE 1.—*Determination of factors by which to multiply scale readings on Leeds and Northrup potentiometer to obtain normal incidence radiation in gram calories*

Date and hour angle	Q	Scale (Eppley)	Factor Q/Eppley	Scale (Clark)	Factor Q/Clark	Means		
						Q	Eppley	Clark
1939								
March 3:								
3:24	1.134	46.0	.0247	-------	-------	-------	-------	-------
	1.133	46.0	247	-------	-------	-------	-------	-------
	1.118	45.0	246	-------	-------	-------	-------	-------
	1.123	45.5	246	-------	-------	-------	-------	-------
	1.134	46.0	247	-------	-------	1.128	0.02466	-------
	1.130	46.0	246	-------	-------	-------	-------	-------
	1.115	45.0	248	-------	-------	-------	-------	-------
	1.133	46.0	246	-------	-------	-------	-------	-------
	1.151	46.5	248	-------	-------	-------	-------	-------
	1.161	46.5	248	-------	-------	1.138	.02472	-------
	1.167	47.0	248	-------	-------	-------	-------	-------
	1.171	47.0	249	-------	-------	-------	-------	-------
	1.197	48.0	249	-------	-------	-------	-------	-------
	1.206	49.0	246	-------	-------	-------	-------	-------
3:10	1.207	48.5	249	-------	-------	1.190	.02482	-------
1:21	1.405	55.5	253	-------	-------	-------	-------	-------
	1.389	54.5	255	-------	-------	-------	-------	-------
	1.383	54.0	256	-------	-------	-------	-------	-------
	1.380	54.0	256	-------	-------	-------	-------	-------
1:16	1.389	55.0	253	-------	-------	1.389	.02546	-------

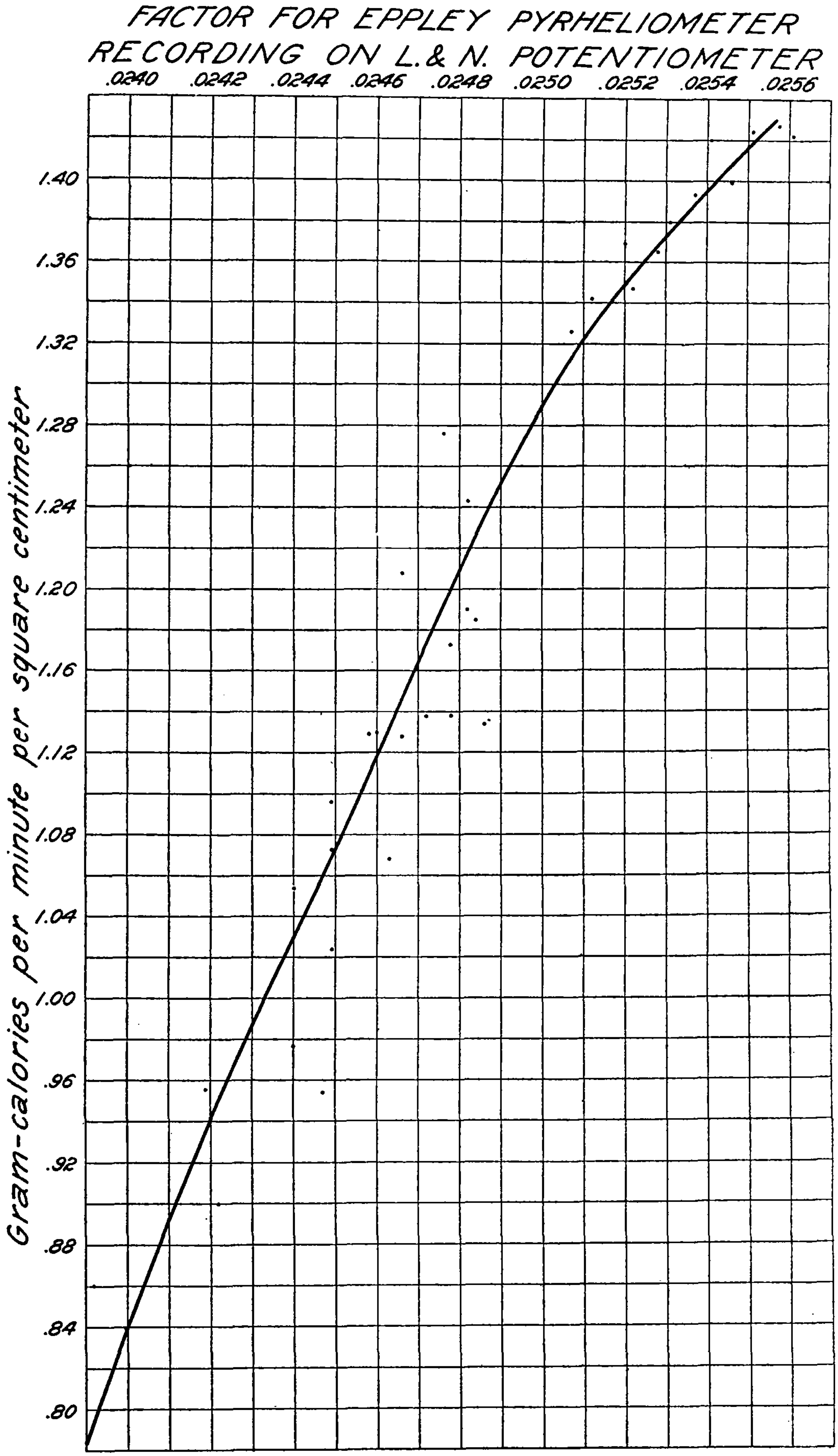

FIGURE 1.—Plot of the mean factors, as abscissas, against radiation values in gram-calories as ordinates, for the Eppley pyrheliometer.

TABLE 1.—*Determination of factors by which to multiply scale readings on Leeds and Northrup potentiometer to obtain normal incidence radiation in gram calories*—Continued

Date and hour angle	Q	Scale (Eppley)	Factor Q/Eppley	Scale (Clark)	Factor Q/Clark	Means Q	Means Eppley	Means Clark
1939								
March 7:								
3:18	1.163	46.8	249	89.4	.0130			
	1.168	47.1	248	89.5	131			
	1.158	47.0	246	89.3	130			
	1.160	47.0	247	89.6	130			
	1.174	47.2	249	89.4	131			
	1.192	47.8	249	89.2	134			
	1.192	47.8	249	89.2	134			
	1.170	47.4	247	89.5	131			
	1.176	47.5	247	89.5	131			
3:09	1.176	47.5	247	89.6	131	1.173	.02478	.01313
2:51	1.263	51.0	248	96.1	131			
	1.289	51.1	252	96.2	134			
	1.290	51.1	252	96.3	134			
	1.285	51.4	250	96.3	133			
	1.276	51.8	246	96.3	133			
	1.267	51.7	245	96.6	131			
	1.273	51.9	245	97.0	131			
	1.274	51.9	245	96.8	132			
2:43	1.266	51.7	245	96.3	131	1.276	.02476	.01332
1:48	1.367	54.5	251	101.0	135			
	1.371	54.5	252	101.5	135			
	1.378	54.5	253	102.5	135			
	1.368	54.5	252	102.0	134			
	1.361	54.0	252	101.0	135			
	1.363	54.0	254	101.0	135			
	1.364	54.5	250	101.0	135			
	1.366	54.5	251	101.5	135			
	1.371	54.5	252	101.5	135			
1:39	1.378	54.5	253	102.0	135	1.369	.02520	.01349
1:20	1.415	55.5	255	106.0	134			
	1.431	56.5	253	106.0	135			
	1.426	56.0	255	106.0	135			
	1.410	55.5	254	106.0	133			
	1.422	56.0	254	105.0	136			
	1.414	55.5	255	105.0	135			
	1.415	55.5	255	105.0	135			
	1.421	56.0	254	105.0	136			
1:11	1.425	56.5	252	105.0	136	1.420	.02541	.01348
0:59	1.410	55.0	256	105.0	135			
	1.403	55.0	255	105.0	134			
	1.404	55.0	255	105.0	137			
	1.433	45.0	256	105.0	138			
	1.441	56.0	257	105.0	138			
	1.448	56.0	258	105.0	138			
	1.433	56.0	256	105.0	137			
	1.420	55.5	256	105.0	136			
	1.414	55.5	255	105.0	135			
0:50	1.411	55.0	257	105.0	135	1.422	.02561	.01363
0:45	1.436	56.0	.0256	106.5	.0135			
	1.420	55.5	256	106.0	134			
	1.423	55.5	256	106.0	134			
	1.417	55.5	255	105.5	134			
	1.422	55.5	256	106.0	135			
	1.431	56.0	256	106.5	134			
	1.432	56.0	256	107.0	134			
	1.447	56.5	256	107.0	135			
	1.439	56.5	255	107.0	135			
0:36	1.427	56.0	255	106.5	134	1.429	.02557	.01344
0:31	1.481	57.5	257	108.0	138			
	1.441	56.5	255	106.0	136			
	1.414	55.5	255	104.0	136			
	1.441	56.5	255	106.0	136			
	1.439	56.5	255	106.0	136			
	1.420	56.0	254	105.0	135			
	1.414	55.5	255	105.0	135			
	1.407	55.0	256	104.0	135			
	1.396	55.0	254	104.0	135			
0:40	1.388	54.5	255	104.0	134	1.424	.02551	.01356
1:45	1.361	54.0	252					
	1.361	54.0	252					
	1.366	54.0	253					
	1.366	54.0	253					
	1.369	54.0	254			1.365	.02528	
	1.300	53.9	252					
	1.328	53.2	250					
	1.323	53.2	249					
	1.338	53.3	251					
	1.359	53.6	254	Off Scale		1.342	.02512	

Date and hour angle	Q	Scale (Eppley)	Factor Q/Eppley	Scale (Clark)	Factor Q/Clark	Means Q	Means Eppley	Means Clark
1939								
March 7:								
1:45	1.371	53.9	254					
	1.363	53.9	253					
	1.345	53.4	252					
	1.333	53.0	252					
	1.323	52.9	250			1.347	.02522	
	1.322	52.9	250					
	1.326	53.0	250					
	1.327	53.0	250					
2:00	1.329	53.0	251			1.326	.02502	
2:37	1.261	50.7	249	93.4	135			
	1.267	50.7	250	93.4	135			
	1.253	50.4	249	93.0	135			
	1.240	50.1	248	92.7	134			
	1.235	50.0	247	92.8	133			
	1.239	50.0	248	92.8	134			
	1.246	50.1	249	92.7	134			
	1.247	50.1	249	92.5	135			
	1.244	50.1	248	92.4	135			
	1.232	49.8	247	92.4	133			
	1.229	49.8	247	92.6	133			
	1.240	50.0	248	92.6	134			
	1.240	50.0	248	92.6	134			
2:50	1.233	40.8	248	92.5	133	1.243	.02482	.01337
March 8:								
1:32	1.389	54.5	255	104.0	134			
	1.384	54.5	254	104.0	133			
	1.394	55.0	253	105.5	133			
	1.415	56.0	253	105.0	135			
	1.405	55.5	253	105.0	134			
	1.395	55.0	254	104.0	134			
	1.394	55.0	254	104.0	134			
	1.375	54.0	255	104.0	132			
	1.389	55.0	253	104.0	134			
1:23	1.391	55.0	253	104.0	134	1.393	.02537	.01337
0:54	1.378	54.5	253	103.0	134			
	1.379	54.5	253	103.0	134			
	1.378	54.5	253	103.0	134			
	1.381	54.5	253	103.0	134			
	1.376	54.5	253	103.0	134			
	1.368	54.0	254	103.0	133			
	1.381	54.0	256	103.0	134			
	1.390	55.0	253	103.0	135			
	1.387	55.0	252	103.0	135			
0:44	1.381	55.0	251	103.0	134	1.380	.02531	.01341
0:28	1.220	49.9	.0246	92.8	.0133			
	1.214	44.9	243	92.8	133			
	1.232	50.0	246	93.0	132			
	1.222	49.0	250	92.8	133			
	1.208	49.2	248	92.2	131			
	1.203	48.2	250	91.2	132			
	1.191	48.1	248	90.6	131			
	1.180	48.0	246	90.2	131			
	1.200	49.0	245	91.6	131			
0:39	1.214	49.8	244	92.0	132	1.208	.02466	.01319
1:14	1.194	47.8	250	88.0	136			
	1.186	47.6	249	88.0	135			
	1.182	47.6	248	88.4	134			
	1.174	47.6	247	89.2	132			
1:18	1.189	48.0	248	89.0	134	1.185	.02484	.01342
1:58	1.143	46.5	246	86.2	133			
	1.150	46.0	246	86.2	131			
	1.133	46.0	246	86.4	131			
	1.137	46.0	247	86.8	131			
	1.137	46.0	247	86.8	131			
	1.133	45.9	247	86.5	131			
	1.126	45.8	246	86.2	131			
	1.117	45.6	245	85.2	131			
	1.114	45.4	245	85.2	131			
2:07	1.111	45.4	245	84.2	132	1.130	.02460	.01313
2:30	1.153	46.4	248	85.6	135			
	1.148	46.2	248	85.6	134			
	1.136	46.1	246	85.6	133			
	1.133	46.0	246	85.6	133			
	1.136	46.0	247	85.5	133			
	1.133	46.0	246	85.3	133			
	1.123	46.0	244	85.2	132			
	1.111	45.8	243	85.0	131			
	1.108	45.3	245	84.8	131			
2:40	1.110	45.3	245	84.8	131	1.129	.02458	.01326
3:07	1.077	43.9	245	82.2	131			
	1.060	43.6	243	82.0	129			
	1.046	43.0	243	81.7	128			
	1.047	42.8	245	81.7	128			
3:11	1.041	49.6	244	81.6	128	1.054	.02440	.01288

TABLE 1.—*Determination of factors by which to multiply scale readings on Leeds and Northrup potentiometer to obtain normal incidence radiation in gram calories*—Continued

Date and hour angle	Q	Scale (Eppley)	Factor Q/Eppley)	Scale (Clark)	Factor Q/Clark	Means: Q	Means: Eppley	Means: Clark
1939								
March 9:								
3:22	0.860	35.8	240	67.8	127			
	0.867	36.1	240	68.2	127			
	0.852	35.8	238	68.0	126			
	0.860	35.8	240	68.4	126			
	0.864	36.0	240	68.7	126			
	0.857	35.8	239	68.6	125			
	0.854	35.8	238	68.4	125			
	0.860	36.0	239	69.4	124			
	0.864	36.2	239	69.6	124			
	0.866	36.2	239	69.7	124	0.860	.02392	.01250
	0.912	37.7	242	71.0	129			
	0.927	37.9	245	71.9	129			
	0.927	38.0	244	71.9	129			
	0.931	38.4	243	72.1	129			
	0.938	38.8	242	72.1	130			
	0.938	39.0	241	74.0	127			
	0.944	39.3	240	74.0	128			
	0.952	39.8	239	74.5	128			
	0.957	39.8	240	74.8	128			
	0.961	40.1	240	76.0	126			
	0.968	40.4	240	75.4	128			
	0.980	40.6	241	75.4	130			
	0.983	40.8	241	75.6	130			
	0.982	40.5	242	76.9	128			
	0.980	40.4	243	77.0	127			
	0.983	40.1	245	77.2	127			
2:51	0.996	40.8	244	77.4	129	0.956	.02419	.01285
2:50	0.998	40.8	.0245	75.8	.0132			
	0.994	41.0	243	76.0	131			
	1.002	41.0	244	76.4	131			
	1.009	41.0	246	77.0	131			
	1.009	41.1	245	77.0	131			
	1.005	41.2	244	77.4	130			
	1.002	41.0	244	77.4	129			
	1.002	40.9	245	77.0	130			
	1.004	40.8	246	76.7	131			
	1.007	40.9	246	76.5	132			
	1.011	41.4	244	77.2	131			
	1.025	41.8	245	77.6	132			
	1.037	42.0	247	77.6	134			
	1.033	42.0	246	78.4	132			
	1.036	42.2	245	78.4	132			
	1.036	42.4	245	78.2	132			
	1.030	42.2	244	78.8	131			
	1.035	42.3	245	79.2	130			
	1.039	42.4	245	78.8	132			
	1.042	42.4	246	78.3	133			
	1.039	42.6	244	78.3	133			
	1.043	42.8	244	78.2	133			
	1.047	42.9	244	79.2	132			
	1.052	42.8	246	78.7	134			
	1.052	42.9	245	79.4	132	1.024	.02449	.01316
	1.055	43.2	244	78.8	134			
	1.058	43.1	246	78.6	135			
	1.061	43.4	244	78.9	134			
	1.062	43.4	244	78.9	135			
	1.059	43.3	245	79.3	134			
	1.058	43.3	244	79.8	133			
	1.056	43.2	244	80.4	131			
	1.054	43.1	245	80.5	131			
	1.057	43.1	245	80.6	131			
	1.067	43.0	248	81.1	130			
	1.076	43.4	248	81.6	132			
	1.070	43.5	246	81.8	131			
	1.067	43.5	245	82.4	130			
	1.070	43.6	245	82.5	130			
	1.070	43.7	245	82.6	130			
	1.073	43.8	245	82.7	130			
	1.077	44.0	245	82.8	130			
	1.080	44.2	244	82.4	131			
	1.081	44.4	243	81.7	132			
	1.086	44.5	244	81.9	133			
	1.093	44.7	245	82.4	133			
	1.099	44.8	245	82.4	133			
	1.103	45.1	245	82.8	133			
	1.103	45.2	244	82.9	133			
2:00	1.102	45.2	244	82.9	133	1.073	.02449	.01324
1:59	1.099	45.2	243	83.8	131			
	1.096	45.0	244	83.3	132			
	1.093	45.2	242	83.9	130			
	1.089	44.8	243	84.3	129			
	1.090	44.5	245	84.6	129			
	1.091	44.6	245	83.8	131			
	1.101	44.7	246	84.4	130			
1:52	1.107	44.8	247	84.9	130	1.096	.02444	.01302
1:22	1.122	45.1	249	84.4	133			
	1.127	45.1	250	84.4	134			
	1.127	45.0	250	84.6	133			
	1.121	45.6	246	84.7	132			
	1.133	45.6	248	84.8	134			
	1.150	45.8	251	85.3	135			
1939								
March 9:								
1:22	1.144	45.8	250	84.8	135			
	1.126	46.1	244	84.9	133			
	1.118	45.8	244	85.4	131			
	1.117	45.8	244	85.2	131			
	1.122	45.8	245	84.8	132			
	1.140	46.1	247	85.9	133			
	1.145	46.1	248	86.2	133			
	1.140	46.2	247	86.0	133			
	1.145	46.3	247	84.9	135			
	1.148	46.3	248	85.7	134			
	1.152	46.2	249	85.8	134			
	1.159	46.4	250	85.7	135			
	1.162	46.5	250	85.6	136			
1:03	1.163	46.5	250	85.5	136	1.138	.02478	.01336
0:52	1.150	46.2	.0249	85.6	.0134			
	1.151	46.1	250	84.3	136			
	1.147	46.0	249	84.1	136			
	1.146	45.8	249	84.6	135			
	1.131	45.3	250	84.5	134			
	1.123	45.6	246	83.2	135			
	1.135	45.4	250	83.0	136			
	1.132	45.2	249	83.0	136			
	1.116	45.1	248	82.4	135			
0:43	1.108	45.1	246	82.2	135	1.134	.02486	.01352
0:37	1.090	43.8	249	79.8	137			
	1.084	43.8	248	79.8	136			
	1.075	43.6	246	79.6	135			
	1.070	43.4	247	79.6	134			
	1.071	43.3	247	79.3	135			
	1.065	43.2	247	79.2	134			
	1.062	43.2	246	79.1	134			
	1.058	43.2	245	79.1	134			
	1.051	43.1	244	79.0	133			
0:46	1.050	43.1	244	79.0	133	1.068	.02463	.01345
1:20	0.977	40.0	244	74.0	132	0.977	.02440	.01320
March 10:								
3:27	0.887	36.0	241	67.4	132			
	0.884	36.7	241	67.4	131			
	0.887	36.7	242	67.6	131			
	0.890	36.9	241	67.7	131			
	0.901	37.0	243	68.4	130			
	0.898	37.4	240	68.6	131			
	0.894	37.4	239	68.7	130			
	0.898	37.4	240	69.0	130			
	0.906	37.3	243	69.0	131			
	0.909	37.0	247	70.2	130			
	0.910	37.2	245	69.8	130			
	0.910	37.3	244	70.0	130			
	0.909	37.4	243	69.8	130			
	0.901	37.3	242	69.8	129			
	0.900	37.3	241	69.8	129			
	0.903	37.3	242	69.6	130			
	0.900	37.3	241	69.2	130			
	0.898	37.2	241	69.0	130			
	0.901	37.1	243	69.2	130			
3:01	0.905	37.1	244	69.3	131	0.900	.02422	.01303
3:06	0.929	37.9	245	71.2	131			
	0.945	38.8	244	72.0	131			
	0.957	39.0	246	73.4	130			
	0.953	39.2	243	73.4	130			
	0.944	38.8	243	73.3	129			
	0.947	38.8	244	72.8	130			
	0.946	38.8	244	73.0	130			
	0.957	39.2	244	73.4	129			
	0.978	39.8	246	74.8	131			
2:57	0.987	39.9	248	74.8	132	0.954	.02447	.01304

TABLE 2.—*Probable errors of individual readings, and of means from lines of best fit and from means of all*

	Probable errors: Range 0.85–1.45 gr.-cal.			Probable errors: Range 0.50–1.50 gr.-cal.		
	Potentiometer		Clark with micro-ammeter	Potentiometer		Clark with micro-ammeter
	Eppley	Clark		Eppley	Clark	
Means from line (variable factor)	±0.24	±0.84	±1.81	±0.40	±1.40	±3.02
Individual readings from line (variable factor)	±0.37	±0.92		±0.62	±1.53	
Means from mean of all (constant factor)	±1.18	±1.31	±2.69	±1.97	±2.18	±4.48

These small probable errors from the line of best fit unquestionably show the need for using variable factors rather than a constant factor. In fact they are as close as would be expected with the regular substandard instruments for the following reasons:

(1) Normal incidence radiation never is uniform at sea level, owing chiefly to turbidity. Waviness therefore in a normal incidence curve, although slight on the best of days, is natural.

(2) In the operation of the Smithsonian silver-disk pyrheliometer the shutter is open for 2 minutes, then closed for 2 minutes. The alternations with the Marvin resistance pyrheliometer occur every minute. It is conceivable under adverse conditions that the shutter might be open during low radiation receipt, or that these conditions might be reversed. It is obvious that an error is introduced when comparing such an instrument against one that gives instantaneous and continuous readings.

(3) Owing to the personal equation it is necessary for each user of a Smithsonian or a Marvin pyrheliometer to personally read the instrument when checking against Smithsonian standards at the Astrophysical Observatory. A change of observers of necessity introduces another small source of error.

(4) While the design of all instruments here mentioned calls for an angular opening of 5°43′, in practical construction it mechanically is impossible to adhere to these measurements perfectly. As the annulus about the sun is by far the brightest portion of the sky, any increase or dimunition of the diameter of this annulus, even very slight, creates an error which is particularly appreciable on hazy days.

(5) The addition of a highly polished thin quartz or glass window over the receiving end of the Eppley and Clark pyrheliometers changes the spectral distribution of energy received on the thermoelectric surfaces enough to produce another small error.

(6) The receiving surfaces of all the pyrheliometers, especially those without sealed windows, undergo slight changes in their absorption coefficients owing to dust and other extraneous material falling upon their surfaces.

(7) Any recording mechanism lacks 100 percent precision owing to several factors, among which may be cited (*a*), nonuniform scale divisions; (*b*), incorrect setting of the zero and pen; (*c*), change in length and width of paper because of humidity variations; (*d*), slight changes in the e. m. f. of the standard cell used with potentiometers; (*e*), irregular rotation of the record roll; (*f*), zero shift for a number of reasons; and (*g*), the gradual lowering of the e. m. f. of the operating battery between checks against the standard cell.

(8) Rapid temperature changes of the free air, and winds of appreciable velocity, vitiate slightly the readings of all phyrheliometers of the types here mentioned.

As previously stated, only those readings made after the potentiometer was thoroughly adjusted to the highest practical efficiency were used in these comparisons. After this adjustment the instrument gave extraordinarily good results as shown by a continuous record, for more than 100 hours, of the e. m. f. generated by the vacuum thermocouple when receiving its energy from a well-seasoned lamp in series with a constant voltage regulator.

In order to minimize errors of paper shrinkage and expansion, a special type of record paper is used which has a low coefficient of expansion.

Although the potentiometer automatically balances the dry cells against the standard cell every 43 minutes, we also make this balance manually immediately preceding each series.

All the other instruments were thoroughly checked and placed in first-class condition before the calibrations. The Smithsonian silver-disk pyrheliometer was checked against Smithsonian standards at the Astrophysical Observatory, and used only twice before the tests; all instruments were realigned, and indicator points re-etched to insure their correct setting on the sun; the Marvin pyrheliometer was checked against the silver-disk; the signal-clock was regulated to run at a uniform rate; the microammeter was tested at the National Bureau of Standards and returned to the factory for replacement of a faulty bearing, after which it was calibrated at the Bureau, and a table giving the true values in microamperes of the scale readings was used to reduce the observations.

Upon first thought it might appear that the logical method of making these tests would be to run the two thermoelectric pyrheliometers against a standard artifical source of radiation. Practical limitations to date have prevented much work along this line, although some tests were made with the vacuum thermocouple at the Bureau of Standards; these were meager owing to lack of a light source of sufficient energy. Moreover, it is impossible practically to obtain a point-source of light; and as yet no artifical source of energy approximates closely the spectral distribution of solar energy.

Attempts to insure a high degree of accuracy have in the past so complicated the apparatus and rendered it so expensive that we have had to limit sharply the number of solar observational stations. It is thought that the newer type of apparatus will relieve this situation. Without doubt the utmost in precision is required in many special researches; but in the case of the Weather Bureau, lack of personnel and equipment prohibit the general use of precision apparatus in the field, although we maintain such instruments at our central observatory, and for general radiation climatology, high precision is not necessary.

Thermoelectric pyrheliometers are especially well adapted for measuring the red and yellow components between 0.61 and 0.51 μ [3] and have been used for this purpose by both this Bureau and the Blue Hill Meteorological Observatory.

Upon completion of the tests, the manufacturers immediately took steps to redesign the thermopile, particularly as to spacing of the elements, so as to decrease the variability of the factor values. While preliminary tests on one of these new pyrheliometers show a marked improvement in performance, the data obtained so far are too meager to give definite results.

[3] Kimball, Herbert H. Determinations of atmospheric turbidity and watervapor content. MONTHLY WEATHER REVIEW 64: 1–5, 1936.

Kimball, Herbert H. and Hand, Irving F. The use of glass color screens in the study of atmospheric depletion of solar radiation. Monthly Weather Review 61: 80–83, 1933.

TABLE 3.—*Comparison between the constant factor and the variable factors of the Eppley pyrheliometer*

(1) Scale [1]	(2) Factor	(3) Gram-calories	(4)	(5) Percent departure of (4) from (3)	(6) Corresponding millivolts
		(1)+(2)	0.0249 ×(1)		
21.0	0.0234	0.491	0.523	+6.5	0.61
23.1	235	.545	.575	+5.9	.67
25.3	236	.597	.630	+5.5	.74
27.5	237	.652	.685	+5.1	.81
29.6	238	.704	.737	+4.7	.88
31.7	239	.758	.789	+4.1	.95
33.7	240	.809	.839	+3.7	1.02
35.8	241	.863	.891	+3.2	1.08
37.8	242	.915	.941	+2.8	1.14
39.8	243	.967	.991	+2.5	1.19
41.4	244	1.010	1.031	+2.1	1.25
43.1	245	1.056	1.073	+1.6	1.31
44.9	246	1.105	1.118	+1.2	1.36
46.9	247	1.158	1.168	+0.9	1.41
48.6	248	1.205	1.210	+0.4	1.45
50.1	249	1.247	1.247	0	1.49
51.4	250	1.285	1.280	−0.4	1.53
52.5	251	1.318	1.307	−0.7	1.57
53.5	252	1.348	1.332	−1.2	1.61
54.4	253	1.376	1.355	−1.5	1.64
55.4	254	1.407	1.379	−2.0	1.67
56.2	255	1.433	1.399	−2.3	1.70
56.9	256	1.457	1.417	−2.7	1.72
57.6	257	1.480	1.434	−3.2	1.74
58.2	258	1.502	1.449	−3.5	1.76
59.0	259	1.528	1.469	−3.8	1.78
59.7	260	1.552	1.487	−4.2	1.80

[1] The recording micromax potentiometer used for this test has a full-scale deflection of 3 millivolts; it therefore is necessary to shift to its alternate 15-milivolt circuit when the needle reaches 100 on the scale.

The probable errors of the values in column 3 do not exceed ±0.3 percent.

Factors to reduce scale readings on potentiometer recording e. m. f. generated by Clark thermoelectric pyrheliometer

Potentiometer	Factors	Gram-calories	Potentiometer	Factors	Gram-calories
Scale readings: [1]			Scale readings:		
40.5	0.0126	0.510	81.8	132	1.080
46.9	127	.596	88.7	133	1.180
54.7	128	.700	98.5	134	1.320
62.0	129	.800	105.2	135	1.419
70.0	130	.910	109.0	136	1.482
76.3	131	1.000	114.0	137	1.562

[1] With potentiometer having full scale deflection of 3 millivolts it is necessary to shift to the 15-millivolt scale when the needle approaches the top of the scale.

Our conclusions are:

(1) Provided factors are determined according to methods here described, thermoelectric pyrheliometers are excellent for laboratory use in making routine measurements with a precision as good as that obtained with a Marvin pyrheliometer, and only slightly under the precision attained with the Smithsonian silver-disk pyrheliometer.

(2) The advantages of the use of this type of instrument are manifold; first, a saving of at least 75 percent in the observer's time; second, the readings are continuous; and third, the simplicity of the whole apparatus eliminates much of the trouble experienced with the accessories necessary for the Marvin pyrheliometer.

(3) The vacuum type is ideal for field use when used with a portable potentiometer, especially when weight is an important factor, as for example, when measurements are desired on high, poorly accessible mountain tops, because the whole pyrheliometer weighs less than 1 pound.

(4) The vacuum pyrheliometer assumes equilibrium within six seconds after opening the shutter; the copper-constantan type requires about 20 seconds to reach equilibrium.

(5) The probable errors are slightly less with the non-vacuum type.

(6) A portable precision eye-read potentiometer is recommended for field use rather than a microammeter, as the former eliminates practically all errors arising from changes in resistance of various units in the electrical circuit.

Additional comparisons made in subzero weather early in 1941 between the Smithsonian silver disk, the Clark vacuum type and the new Eppley pyrheliometers show (1) much less variation in the factors for the new Eppley pyrheliometers with widely-spaced elements, and (2) a slight free-air temperature effect; that is, all the thermoelectric pyrheliometers tested show greater efficiency with very low free-air temperatures.

ADJUSTMENT OF AIRPORT STATION-PRESSURE RECORDS TO FORMER CITY STATION ELEVATION

By W. W. REED

[Weather Bureau, Washington, D. C., January 1941]

In the installation of mercurial barometers at the airports, the tables for reduction of station pressure to sea level were based in most cases on a station elevation corresponding exactly, or very nearly, to the elevation of the ivory point of the barometer, or to the level 8 feet above the landing field. In only a relatively few cases was the adopted station elevation made to coincide with the station elevation at the city office.

At city offices established prior to 1900, the practice has been followed since the beginning of that year of maintaining a single "station elevation" by applying a "removal correction" whenever the barometer was moved to a different elevation from that existing on January 1, 1900, so that the "station pressures" pertained to the actual elevation as of that date. Thus the adopted "station elevation" corresponded to the actual elevation of the ivory point of the barometer at the beginning of the current century. At city offices established subsequent to January 1, 1900, the adopted "station elevation" was almost invariably the actual elevation of the barometer when the station was first established. Under this system, records of "station pressure" at city offices have been directly comparable since the dates in question by virtue of the fact the data were pertinent to a single "station elevation."

However, where city offices were closed or consolidated with the airport stations, the changes in elevation were so considerable in many cases that it was inadvisable to attempt the employment of a "removal correction" and the airport "station elevations" were maintained.

Beginning with July 1939, and prior thereto at several stations, the records of pressure at most of the airports were made official for synoptic purposes and published in the MONTHLY WEATHER REVIEW. This procedure introduced into the homogeneity of pressure records breaks that range in value from a few thousandths of an inch, insignificant for practical purposes, to more than 0.50 inch locally in winter. In view of the need for homogeneity in respect to elevation in the study of pressure trends, action has been taken to prepare adjustments for